Business Intelligence Modeling in Launch Operations

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ABSTRACT

This technology project is to advance an integrated Planning and Management Simulation Model for evaluation of risks, costs, and reliability of launch systems from Earth to Orbit for Space Exploration. The approach builds on research done in the NASA ARC/KSC developed Virtual Test Bed (VTB) to integrate architectural, operations process, and mission simulations for the purpose of evaluating enterprise level strategies to reduce cost, improve systems operability, and reduce mission risks. The objectives are to understand the interdependency of architecture and process on recurring launch cost of operations, provide management a tool for assessing systems safety and dependability versus cost, and leverage lessons learned and empirical models from Shuttle and International Space Station to validate models applied to Exploration. The systems-of-systems concept is built to balance the conflicting objectives of safety, reliability, and process strategy in order to achieve long term sustainability. A planning and analysis test bed is needed for evaluation of enterprise level options and strategies for transit and launch systems as well as surface and orbital systems. This environment can also support agency simulation based acquisition process objectives. The technology development approach is based on the collaborative effort set forth in the VTB's integrating operations, process models, systems and environment models, and cost models as a comprehensive disciplined enterprise analysis environment. Significant emphasis is being placed on adapting root cause from existing Shuttle operations to exploration. Technical challenges include cost model validation, integration of parametric models with discrete event process and systems simulations, and large-scale simulation integration. The enterprise architecture is required for coherent integration of systems models. It will also require a plan for evolution over the life of the program. The proposed technology will produce long-term benefits in support of the NASA objectives for simulation based acquisition, will improve the ability to assess architectural options verses safety/risk for future exploration systems, and will facilitate incorporation of operability as a systems design consideration, reducing overall life cycle cost for future systems. The future of business intelligence of space exploration will focus on the intelligent system-of-systems real-time enterprise. In present business intelligence, a number of technologies that are most relevant to space exploration are experiencing the greatest change. Emerging patterns of set of processes rather than organizational units leading to end-to-end automation is becoming a major objective of enterprise information technology. The cost element is a leading factor of future exploration systems.

Keywords: Business intelligence, cost modeling, risk and reliability model, planning and scheduling, space vehicle launch operations

1. INTRODUCTION

Affordability and accurate cost estimation are fundamental to support a sustained program of exploration. According to the Congressional Budget Office[7], ``fulfilling the exploration mission's objectives might require either adding about 32 billion US Dollar to NASA's budgets or extending the schedule for the lunar landing by three to four year[8,9,14]." Business Intelligence modeling in launch operations is being integrated in to a Virtual Enterprise Exploration Testbed (VEET). This VEET is an integrated Planning and Management technology and will produce long-term benefits in simulation-based acquisition. It supports the NASA objectives for improved ability to assess architectural options verses safety and risk of future exploration systems. VEET will facilitate operability of the system design and will reduce the overall life-cycle cost of future launch systems. VEET focuses on the future of NASA as an intelligent system-of-systems real-time enterprise[1,13]. It focuses on three key elements: business intelligence (BI)[13], the Virtual Test Bed (VTB) for launch

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operations[1], and cost/risk/reliability[12]. BI is focused as an integral component of space exploration, and will develop a number of business intelligence technologies that are most relevant to space exploration. BI developments are plentiful in world-leading enterprises and they are experiencing the greatest changes in present times due to the advantages that they bring into today's competitive markets. These developments provide a unique opportunity for NASA's exploration enterprise, which we can bring into our business. Emerging patterns of sets of processes rather than organizational units leading to end-to-end automation is becoming a major objective of enterprise information technology. The VTB focuses on the integration of complex operations in a real-time, web based, and secured user-friendly collaborative environment. The VTB architecture relies on proven technologies present in today's business world. The VTB will integrate particular operations and activities of space exploration and missions, providing a foundation for BI and NASA's operations. The technical challenges are addressed through activity-based and advanced modeling of launch operations.

This VEET Technology-Systems Analysis effort proposes to provide high-level technology analysis tools, and integrated analysis of the potential system and/or architecture impact of new technologies. BI is defined as an interactive process of analyzing and exploring structured, domain-specific information (stored in a Knowledge Base or Data warehouse) to discern trends or patterns, thereby deriving insights and drawing conclusions. The BI process includes communicating findings and effecting change.

The objective is to create an Integrated Planning and Management (IPM) simulation environment for evaluation of risks, costs, and reliability of launch systems from Earth to Orbit for Space Exploration. This environment will provide a technology foundation for BI within the Exploration Enterprise, with the goal of providing tools and practices that will provide a comprehensive management approach for assessing safety, and dependability versus cost. The scope of the VEET will encompass spacecraft ground test, launch, near-earth operations, interplanetary transit, and Lunar/Mars surface operations. The results of this technology development will establish the architecture for intra-Agency BI that supports the near-term Exploration mission needs and provides a foundation for long-term evolution and supportability through enhanced strategic situation awareness.

2. INTEGRATED PLANNING AND MANAGEMENT APPROACH

Integrated Planning and Management (IPM) has become an important and integral part of present organizations in major worldwide companies[13]. IPM provides a relevant competitive advantage to efficiently plan, control and acquire systems, operations and services, and evaluate and explore components and integral systems. IPM has grown from a set of information technologies (IT) into BI with multiple enterprise applications and models running in real-time on a variety of platforms. The rewards of connecting them and connecting multiple databases are self-evident. IPM will facilitate the creation, distribution, and use of information throughout the Exploration program leading to an advanced intelligent real-time enterprise. The Exploration program needs an intelligent real-time enterprise (IRTE) reflecting the growing importance of technical requirements, the need to make informed decisions and the need for real-time responsiveness. The sustainability strategic objectives drives NASA to eliminate information lag and make more timely and effective decisions. NASA's commitment to excellence and safety requires the IRTE[1]. Businesses today are increasingly organized, managed and automated around a set of processes. BI capabilities are gradually being built into the applications used to automate these processes, as well as into specialty BI tools and applications. "One NASA-IPM" will require establishing a common language, or semantic, in an integrated system. Common semantics are required for strategic management information terms such as invoice, and categories of expenses. They must 'mean' the same thing, from an accounting point of view, in all divisions and in all directorates across NASA Exploration. The common semantic for the entire NASA establishes consistency in terminology and understanding, and eliminates redundant information, just as is the case in implementing a common chart of accounts.

Looking a little closer at the Finance example discussed above, an integrated "One NASA-IPM" system will provide software modules that implement the various operations and accounting functions-such as assembly, payload, accounts, payroll, budgeting, and financial reporting-in a coordinated manner. For example, the data entered into one module is used in the others, thereby eliminating duplicate data entry and reducing errors. And the look and feel of the different module is the same, so users can apply what they know from one module to the others, saving time and easing frustration. Integrated accounting applications can anticipate the needs of Exploration, with features such as forecasting, trend analysis, flexible reporting tools, virtual close capability, and a high degree of automation. Domain knowledge will be collected and organized into an Exploration domain ontology. Domain knowledge will be mapped into software engineering technologies, including derivation of metadata that can be used to derive meaning, insight, and actionable strategic Exploration information related to the interrelationship of systems, missions, and economics. The metadata can then be accessed or pushed to stakeholders and decision makers using the BI architecture framework.

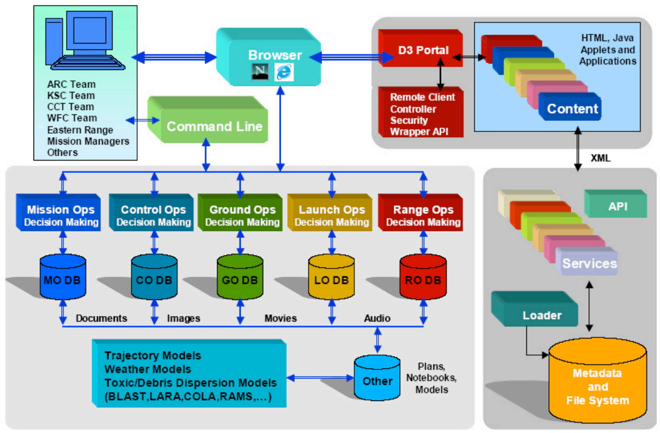

Fig. 1. Virtual Enterprise Exploration Testbed - Outline

3. VIRTUAL ENTERPRISE EXPLORATION TEST BED ARCHITECTURE

VEET will use a 3-tier client/server architecture pattern: Presentation (web-browser), Logic (models, applications) and Information Knowledge Base as shown in Figure 1. Central to this pattern is the Internet[1]. The Internet has created a ubiquitous infrastructure for global, local, intra-enterprise and inter-enterprise connectivity. The Internet and the emergence of new data interchange standards allow relevant information to be produced in an agreed-upon format and shared across organizational and geographical boundaries. The product is enhanced with more business information being generated and distributed.

3.1 Tier 1 User Interface/Presentation

The presentation, or user interface, tier manages the integration with Exploration end users, including the forms and other methods of capturing data from users. The use of a web browser as a universal client that can access multiple client/server applications avoids the need for application-specific software to be installed. The application logic needs to include a Hypertext Transport Protocol (HTTP) interface, and the functionality provided by the presentation layer must be limited to what a web browser is capable of doing (typically using a forms-based interface similar to the ones found on many web sites). Using the browser with a plug-in such as a Java applet or ActiveX control can extend this web-based architecture. This process extends the functionality of the client software, which can provide capabilities such as data validation or even significant parts of the application logic. The use of the web eliminates, almost entirely the need for installing and maintaining presentation software at the client side.

3.2 Tier 2 Logic/Models/Application Server

The logic tier comprises the applications and/or functional components of mission, systems, and economic models of Exploration operations. The VEET application server will be completely abstracted, so it may be altered without requiring changes to data structures, connectivity, or presentation logic. In this scenario, application services and components consist of declarative statement-driven program logic that manipulates application data or domain knowledge. These declarative statements are incorporated into the application class libraries. While the object oriented approach is ideal, the reality is legacy modeling codes function differently. In this type of scenario, an adapter is required to convert the input/output into a native format. Tier 2 hosts the BI applications, VTB simulation environment, and cost, risk, and reliability analysis models. Web services will provide necessary semantics and adapters or agents to manage information exchange between tiers. They will provide BI portal access and security access controls, and client administration.

3.3 Tier 3 Information Knowledge Base

The information knowledge base tier comprises the databases that contain the structured information, in the form of Exploration metadata, used and stored by the application server. The data tier interacts with the logic through data/database management systems software, or adapter agents that provide data access using interfaces such as structured query language (SQL, XSQL), XML Query Language (XSQL), Java database connectivity (JDBC), and others. The data tier handles functions such as data synchronization or transfer between a series of data stores for replication, backup, and data warehousing. The knowledge base will be constructed from a spiral elicitation process that defines the domain features, relationships, and concepts that will be mapped VEET software and meta data. An important out come of producing the VEET knowledge base will be the formal definition of Exploration domain specific semantics, the basis for achieving interoperation data integrity and the specifics for creation of meta data that is visible to the BI tools.

3.4 Why use a Business Intelligence Architecture Approach?

The commercial market place has accepted business intelligence as a required part of the strategic enterprise strategy. For example, similar to the proposed VEET, Oracle applications release 11i has a three-tier architecture supporting distributed multiple services. The Oracle applications architecture consists of a database tier for managing data and providing access to data, an applications tier for managing business logic, processing and related tools, and desktop tier for user interface. The desktop tier is primarily an Internet browser with an Oracle plug-in. As shown in Figure 2, other major industry players, such as PeopleSoft, SAP, and Seibel have evolved their enterprise application architectures to support multi-tier services that support knowledge acquisition, transformational synthesis, and push and/or pull information delivery using an Internet connectivity strategy.

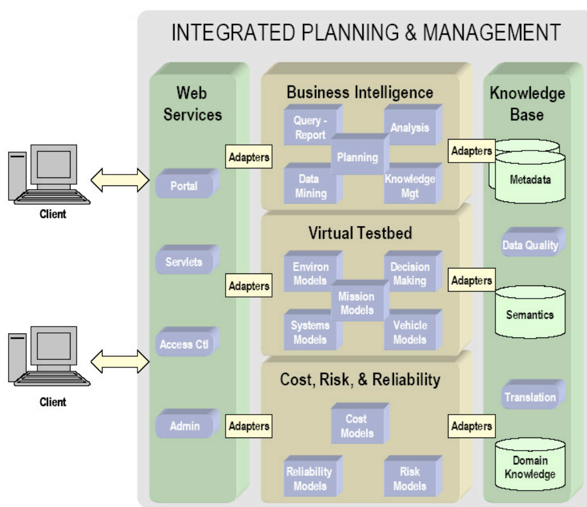

Fig. 2. Business Intelligence Architecture.

The technologies common to all of these architectures, in addition to Internet connectivity, include: Support for Java as a development platform, separation of presentation and business logic, multiple connectivity schemes such as RFC, HTTP, HTTPS, SMTP, and SOAP or other XML based messaging strategies, support for XML metadata, and third party application support. Also, standards have played a significant role in enabling the BI frameworks to evolve, particularly with regard to web services and knowledge management.

4. BUSINESS INTELLIGENCE

The future of business intelligence of space exploration will focus on the intelligent system-of-systems real-time enterprise[13]. In present business intelligence, a number of technologies that are most relevant to space exploration are experiencing the greatest change. Emerging patterns of set of processes rather than organizational units leading to end-to-end automation is becoming a major objective of enterprise information technology, as it is shown in Fig. 3. The cost element is a leading factor of future exploration systems. The intelligent system-of-systems real-time VEET enterprise requires innovation and implementation of BI tools and architectures based on the modern structures of successful global corporations. The proposed BI tools will automate the process of aggregating operations data, analyzing it, and distributing the resulting information to decision-makers. BI has evolved into comprehensive performance monitoring technology that enables real-time decision making for all levels within the enterprise. BI benefits include flexibility and agility, accuracy, focus alignment, and lower costs. The business planning capabilities of business intelligence will provide flexibility and agility, excellent support for management decisions on acquisitions and other key aspects of NASA's operations. Business technology initiatives will provide NASA with greater accuracy in reporting, and finer levels of precision in forecasts and performance goals, a key to mission success in today's environment. Enterprise performance management aligns the focus of the organization and will facilitate the individual responsibility and accountability that must happen for NASA to focus attention on the issues, metrics and value creating activities that matter most to the mission needs. BI's tools lower costs and can significantly cut down on the amount of management time devoted in traditional organizations to planning, budgeting and reporting (estimated to be up by 30 percent). For example, the US state department uses business intelligence applications to integrate data from FBI, CIA and foreign governments. Many key technologies used in the proposed BI have their origins in data warehousing[1,15]. These include the presentation techniques of query and reporting and data visualization, as well as the analytic techniques of online analytical processing and data mining. Query and reporting tools are used to extract data from data warehouses and operational databases, summarize and aggregate it and present it in a desired format. Data visualization is used to provide visual representations of data, enabling users to see large amounts of data with multiple data dimensions or data with strong geographical or spatial elements, and turn such data into tangible information. It allows users to view multiple analytical results in a single, interactive interface and to compare and contrast these findings to make better-informed decisions.

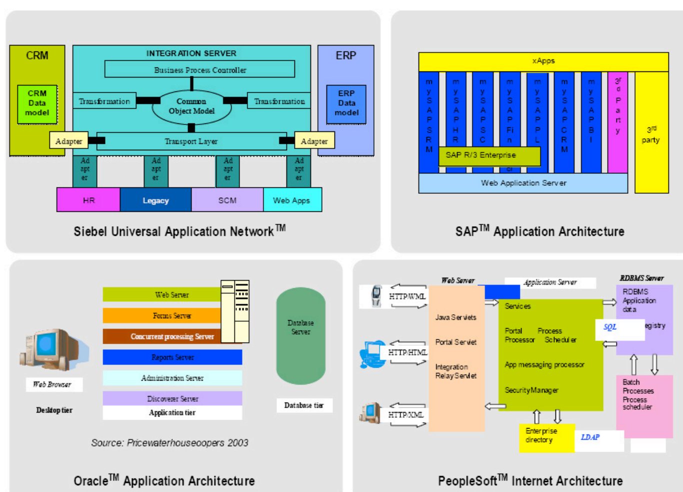

Fig. 3. Commercial BI Architecture Framework.

Exploration Online Analytical Processing (OLAP) will enable users to analyze data across multiple dimensions, using key performance indicators (KPI) to measure important mission activities. These KPIs require the use of metrics that can analyze divisions, project goals and time. Data Mining applies advanced statistical analysis techniques and algorithms to generate business insight. Data mining uses techniques drawn from artificial intelligence[15], statistics, mathematics and modeling to uncover important patterns and trends that are otherwise difficult or impossible to discern using general query and reporting tools or OLAP techniques. Data mining can be used to create models to analyze extremely large numbers of transactions in order to understand the complexity of mission operations. The distinctive ability of Real-Time BI is to analyze real-time operational transaction data as well as warehoused data to identify patterns and trends, and draw comparisons, in a defined context. The real-time business intelligence provide Exploration decisions makers with a perpetually up-to-date risk profile by integrating transactions and activities from different channels with historical data to approve or reject new transactions. Real-time BI reduces the information latency associated with conventional data analysis and provides the capability to place increasing emphasis on individual transactions or small group of transactions. It includes alerts and event notifications, business activity monitoring, and digital dashboards with a larger group of transactions. Conventional BI uses a pull model for information access. The user pulls, or actively generates, the information by executing an ad hoc query or running a predefined report. Real-time BI uses a push model for information access. The applications push, or automatically deliver, results to end users and other applications in the form of automated alerts or digital dashboards.

The primary innovations of the VEET project with real-time BI can be classified into three categories:

- focus: technology, and organization
- types: incremental or radical, spiral development and
- sources: technology transfer or development of new models/concepts for forecasting via internet

These areas are addressed in the following ways:

Business Innovation: Business innovation involves a wide spectrum of original concepts (legacy concepts), including development of new business models (unified decision making approach), organizational innovation (one NASA), business application of technology and communications (Internet), new management techniques, environmental efficiency, new forms of stakeholder participation, transport and finance.

Strategy Innovation: Strategy innovation is to help NASA to develop new value added cost estimation services, enter new cost risk analysis, new distribution methods via internet, and new forms of interaction with many corporations and small businesses.

Modeling/ Service Innovation: Modeling/service innovation is the result of bringing to life a new way to solve the NASA's cost estimation problem - through a VEET development - that benefits NASA and the corporations involved in any space mission cost estimation and risk mitigation.

Process Innovation: Process innovations reduce costs, improve efficiency, and raise productivity. For NASA, process innovations enable them to introduce ``front office'' with new services in cost estimation and cost risk mitigation, so that mission managers can understand underlying process of cost forecasting.

Technology Innovation: Technological innovation covers innovation derived from research and technology developments that are independent of modeling and service initiative. The technology road maps are matched to their modeling road maps to ensure that the two are synchronized. The technology innovation is based on internet network effects, open platform approach, connectivity and interactivity, virtual display of cost modeling results and speed and frequency of exchanges.

Organizational Innovation: Organizational innovation reflects the recognition that new ways of organizing cost estimation in areas such as work-force management, knowledge management, value chain management, external customer partnership, distribution, finance, etc. can improve NASA’s competitiveness and goals.

Cost Reduction - Innovation as an Engine: The speed and efficiency of the diffusion of innovation in many aspects through the economy is critical to achieve NASA’s goals. It can be pictured as a cascade process that is translated into spiral design of system-of-system developments. Through the forces of competition and imitation, an initial innovation is developed and improved so that the impact on the cost and risk is many times greater than that brought about by the earlier application of the innovation of cost modeling in NASA.

Encouraging the emergence of business intelligence coupled with cost, risk and reliability models is a strong force for innovation in many space missions. VEET will be a new enterprise with rapid growth potential that can be the most innovative approaches in cost, risk and reliability, forcing established enterprises, divisions and NASA centers to respond to the strategic information shift by becoming more innovative in cost reduction in any space flight mission.

5. VIRTUAL TEST BED

The VEET approach builds on research done in the ARC/KSC developed Virtual Testbed (VTB) to integrate space operations technologies, methods, architectures, processes, and mission simulations for the purpose of evaluating enterprise level strategies to reduce cost, improve systems operability, and reduce mission risks for future space systems[1,3,4,17,17]. Originally funded by the NASA Computing, Information and Communications Technology (CICT) Program, VTB is a real-time web-based command and control, communication, and intelligent simulation environment of ground, vehicle, and range operations[1](see Fig. 4). The VTB was conceived to address the challenge to modernize launch, range and spaceports into advanced systems for efficient, safe and reliable space exploration missions, and to bring heterogeneous and dispersed human expert teams into one mission. This capability allows cross-functional business process automation by encapsulating pieces of operations and applications into a single flow system. The VTB integrates indigenous research in areas of artificial intelligence (AI), information technologies (IT) and human-centered computing (HCC) in a Web-based secure environment.

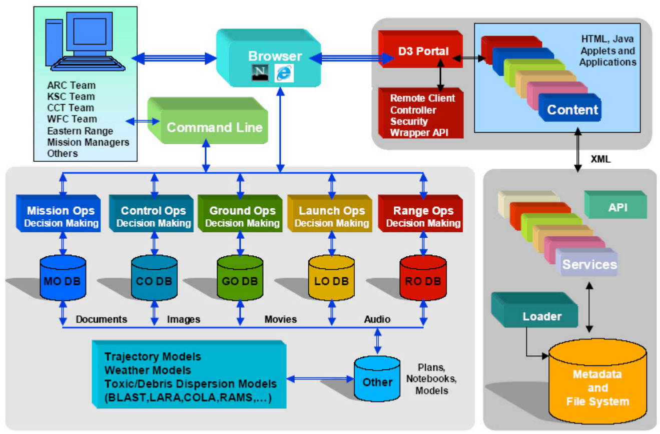

Fig. 4. Virtual Test Bed Architecture.

VTB is a "Model-Based Design" system that integrates knowledge-based and activity-based modeling concepts, innovative analysis methods, and performance metrics in space operations. Its "Multi-modal Interfaces" provide effective and innovative displays to highlight complex causal relations of operations, decisions, command and control operations, equipments, instrumentations and diverse human activities. VTB reduces complexity, cost and planning, processing and training time. It supports evaluation of new operational processes and procedures within a low-risk environment. One of the present capabilities of the test bed simulate the operations of the Space Shuttle Vehicle at NASA Kennedy Space Center. The shuttle simulations support a wide variety mission scenarios with supporting ancillary models for weather, lightning, toxic gas dispersion, debris dispersion, vehicle telemetry, trajectory, ground and payload operations[3,4 17,17]. The test bed framework is robust, and scalable, allowing rapid integration of new cross-platform models. The VTB will provide an excellent working framework for developing a new generation of simulations that can more accurately predict the complex interactions of Exploration mission operations under a variety of operating conditions. The maturity of information and space technology brings a new era of simulation techniques of Exploration systems in a distributed environment. In order to support our proposed VEET concept, the VTB will require adapters for integration with the VEET Knowledge Base, and the IPM Web Services.

6. COST, RISK AND RELIABILITY MODELING

The technology development approach is to build on the collaborative effort set forth in the VTB integrating Exploration operations process models, systems and environment models, and cost models as a comprehensive disciplined enterprise analysis environment. Significant emphasis will be placed on adapting root cause from existing Shuttle operations to exploration. Accomplishing reliability and safety in rockets and spacecraft is extremely complex, and to achieve reliability and safety with economy is even harder. It requires the utilization of techniques that differ considerably from the methods used to achieve reliability at the beginning of the space age. It also requires careful attention to the relationship among cost, schedule, and technological complexity. This objective will be achieved with the integrated Planning and Management (IPM) simulation model for Space Exploration.

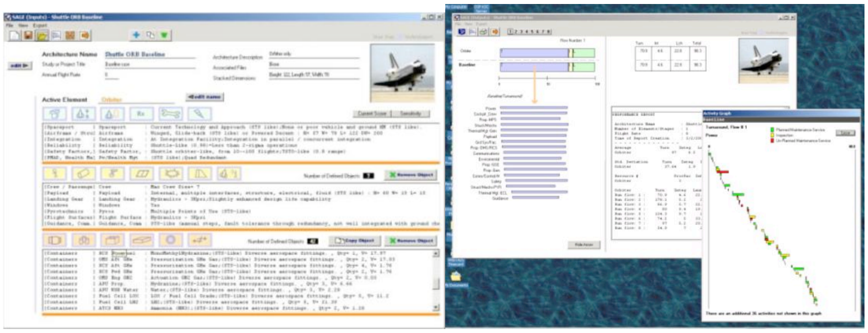

Fig. 5 SAGE, Schedule and Activity generator / Estimator Software Tool

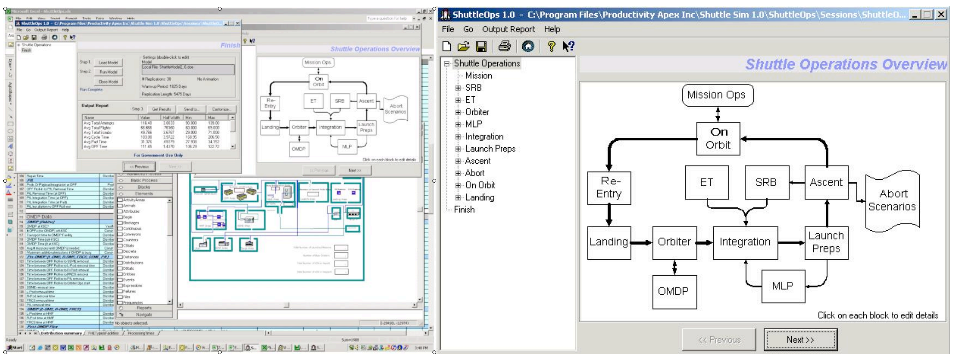

Fig. 6 Shuttle-Ops, Shuttle Operations Simulation

There are a number of activity-based cost models available and in development at Kennedy Space Center[12] and other organizations, as it is shown in Fig. 5 and Fig. 6. Four very relevant models[12,18,5,6] are GemFlo, Shuttle-ops, SAGE and AATe . GemFlo (Generic Simulation Environment for Modeling Future Launch Operations) can model both current and future space transportation systems, including reusable or expendable elements and combinations thereof, to provide system capacity in number of flights per year and facility utilization. Shuttle-ops can be used to explore changes to a Shuttle ground operations process yielding answers within minutes for a number of factors such as facility usage, vehicle fleet size, and off-nominal probabilities, including loss of vehicle or alternate launch site landings. SAGE is an operations assessment methodology tool that, based on the vehicle design parameters and characteristics, generates an activity set and schedule for ground operations. AATe is an MS Excel based application using an intuitive and friendly user interface to define the design of each stage of a reusable launch system, and it works ideally for reusable boosters defined at a very conceptual level. The main advantages of existing models are that these models are based on the discrete event simulation model paradigm. They can be integrated with other models and their encapsulated knowledge can be used by other applications in the VEET. The existing models are excellent for a small group performing cost analysis rather than an enterprise like NASA or exploration office. The main disadvantages of these models are their primitive nature, which can hardly address system of system developments for future mission cost modeling and analysis. Their software is based on the MS Windows operating system, and each one has its own capabilities and limitations, not robust and scalable. The models do not support collaboration and further expansion is limited. The present models are not based on strong database, or metadata concepts. The underlying structure and basic assumptions of the models do not address an exhaustive model analysis (Arena is procedural oriented (no concept of object orientation) and no concept of distributed/parallel simulation). Inputs show dependency on specific function type distributions, and no direct acceptance of physical model real-time results. ARENA's discrete event modeling approach cannot address continuously evolving NASA's future mission concepts. The human expertise has not been included in the present models. In the cost analysis, there are no drill down data warehousing and data mining techniques. From the existing cost models, there is no risk assessment of cost and uncertainty analysis is lacking. In order to support the VEET concept, adapters will be required to integrate these legacy models to the VEET Knowledge Base and to limited Web Services.

Technical Challenges

Technical challenges include cost model validation, integration of parametric models with discrete event process and systems simulations, and large scale simulation integration. A reference enterprise architecture will be required for coherent integration of systems models. It will also require a plan for evolution over the life of the program.

Cost Model Validation

Simulation activity-based cost models[6,10] estimate program cost and how the costs of individual processes are affected by programmatic decisions. Subsystem process simulation relies on subsystem level cost, program/project documentation, flow model, and discrete events calibrated against actual program experience. Cost model validation will initially be based on comparative analysis of Shuttle Root Cause data. As the VEET matures, and historical data evolves for Exploration, improved benchmarks will be available maturing model accuracy.

Integration of Diverse Simulations

The success of this advanced technology of the Virtual Exploration Enterprise Testbed (VEET) is based on addressing the technical challenge of affordability of each operation, component, system, and system-of-systems within a spiral development of the ground and launch operations to low Earth orbit. The findings of the Congressional Budget Office[7] in September 2004 ``suggest that carrying out the exploration mission may require either more funding or extended schedules thoroughly an additional 61 billion USD or a delay in the first lunar return landing of about seven years." The cost projections are based on analogies with past missions, and they do not include advances in technologies and structural changes within NASA and the economy. The VEET provides the opportunity to address these issues, and to produce a significant impact in future NASA missions.

7. CONCLUSIONS

This technology will produce long-term benefits in support of NASA’s objectives for simulation-based acquisition, will improve the ability to assess architectural options verses safety/risk of future exploration systems, and will facilitate incorporation of operability as a systems-design consideration, reducing overall life-cycle cost for future systems. VEET provides a critical capability necessary for Exploration. For sustained space exploration to be successful each mission must succeed within the proposed cost budget, the VEET can be applied early on to a wide variety of mission systems, including the Crew Exploration Vehicle (CEV). Specifically, the VEET has the potential to provide technological solutions satisfying affordability, reusability and modularity, reliability, safety and autonomy. The technical challenges of modularity and reusability will continue to be embedded in the VEET as a condition to address the complexity of the systems. The BI tools will address database, logistics, resource utilization, and efficient allocation of resources. This integrated system benefits the reduction of redundancy of operations, and provides a high degree of autonomy in the system throughout each cell by addressing the task complexity, the robustness to unexpected circumstances, and the level of human operations. The accessibility of information is fundamental to realize the fundamental challenge of safety and reliability, and a system as safe as reasonable to achieve, reducing the risk associated with each operation. The VEET and BI capabilities for forecasting of likely near-future states and technology innovations will have a major impact on cost and safety in exploration missions.

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